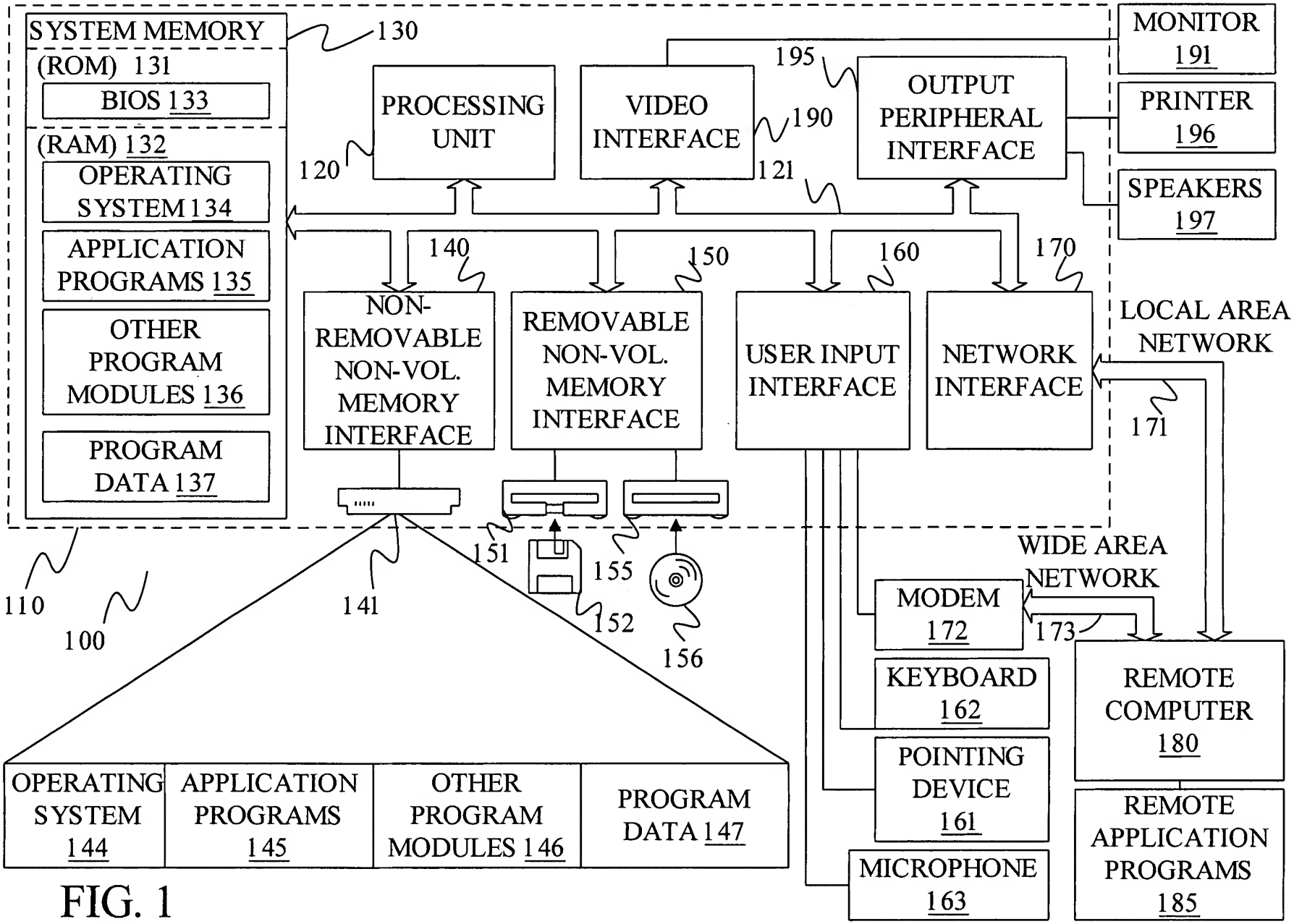
SYSTEM MEMORY
130
(ROM) 131
BIOS 133
(RAM) 132
OPERATING SYSTEM 134
APPLICATION PROGRAMS 135
OTHER PROGRAM MODULES 136
PROGRAM DATA 137
PROCESSING UNIT
120
VIDEO INTERFACE
190
195
OUTPUT PERIPHERAL INTERFACE
121
MONITOR 191
PRINTER 196
SPEAKERS 197
140
150
160
170
NON-REMOVABLE NON-VOL. MEMORY INTERFACE
REMOVABLE NON-VOL. MEMORY INTERFACE
USER INPUT INTERFACE
NETWORK INTERFACE
LOCAL AREA NETWORK
171
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100
141
151
155
152
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173
KEYBOARD 162
POINTING DEVICE 161
MICROPHONE 163
REMOTE COMPUTER 180
REMOTE APPLICATION PROGRAMS 185
OPERATING SYSTEM 144
APPLICATION PROGRAMS 145
OTHER PROGRAM MODULES 146
PROGRAM DATA 147

FIG. 1

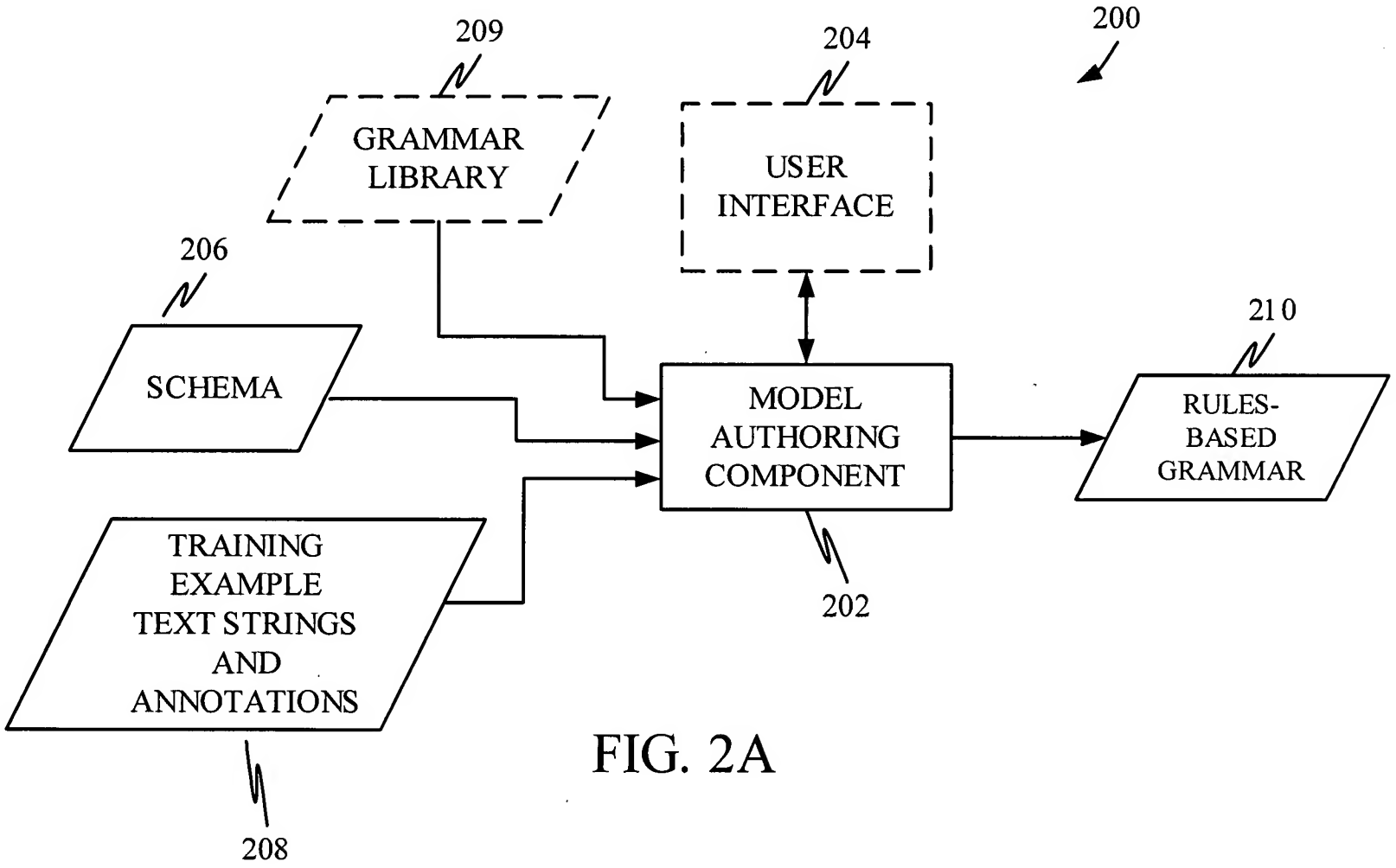

200
209
GRAMMAR LIBRARY
204
USER INTERFACE
206
SCHEMA
MODEL AUTHORING COMPONENT
210
RULES-BASED GRAMMAR
TRAINING EXAMPLE TEXT STRINGS AND ANNOTATIONS
202
208

FIG. 2A

212

```
<Command type="ShowFlight">
    <slot type="Flight"/>
 </command>
 <object type="Flight">
    <slot type="Time" name="Depart"/>
    <slot type="Time" name="Arrival"/>
    <slot type="City" name="Depart"/>
    <slot type="City" name="Arrival"/>
 </object>
```

FIG. 2B

1. <ShowFlight> → <ShowFlightCmd><ShowFlightProperties>
2. <ShowFlightProperties> → <ShowFlightProperty><Opt.><ShowFlightProperties>
3. <ShowFlightProperty> → <ShowFlightPreFlight><Flight><ShowFlightPostFlight>
4. <Flight> → <FlightProperties>
5. <FlightProperties> → <FlightProperty><Opt.><FlightProperties>
6. <FlightProperty> → <FlightPreDepartureCity><City><FlightPostDepartureCity>
7. <FlightProperty> → <FlightPreArrivalCity><City><FlightPostArrivalCity>
8. <FlightProperty> → <FlightPreDepartureTime><Time><FlightPostDepartureTime>
9. <FlightProperty> → <FlightPreArrivalTime><Time><FlightPostArrivalTime>

⋮

FIG. 2C

213

"Flight from Seattle to Boston"

214

```
<ShowFlight>
    <Flight>
        <City name = "Arrival">
            <Boston>
        </City>
        <City name = "Departure">
            <Seattle>
        </City>
    </Flight>
</ShowFlight>
```

FIG. 2D

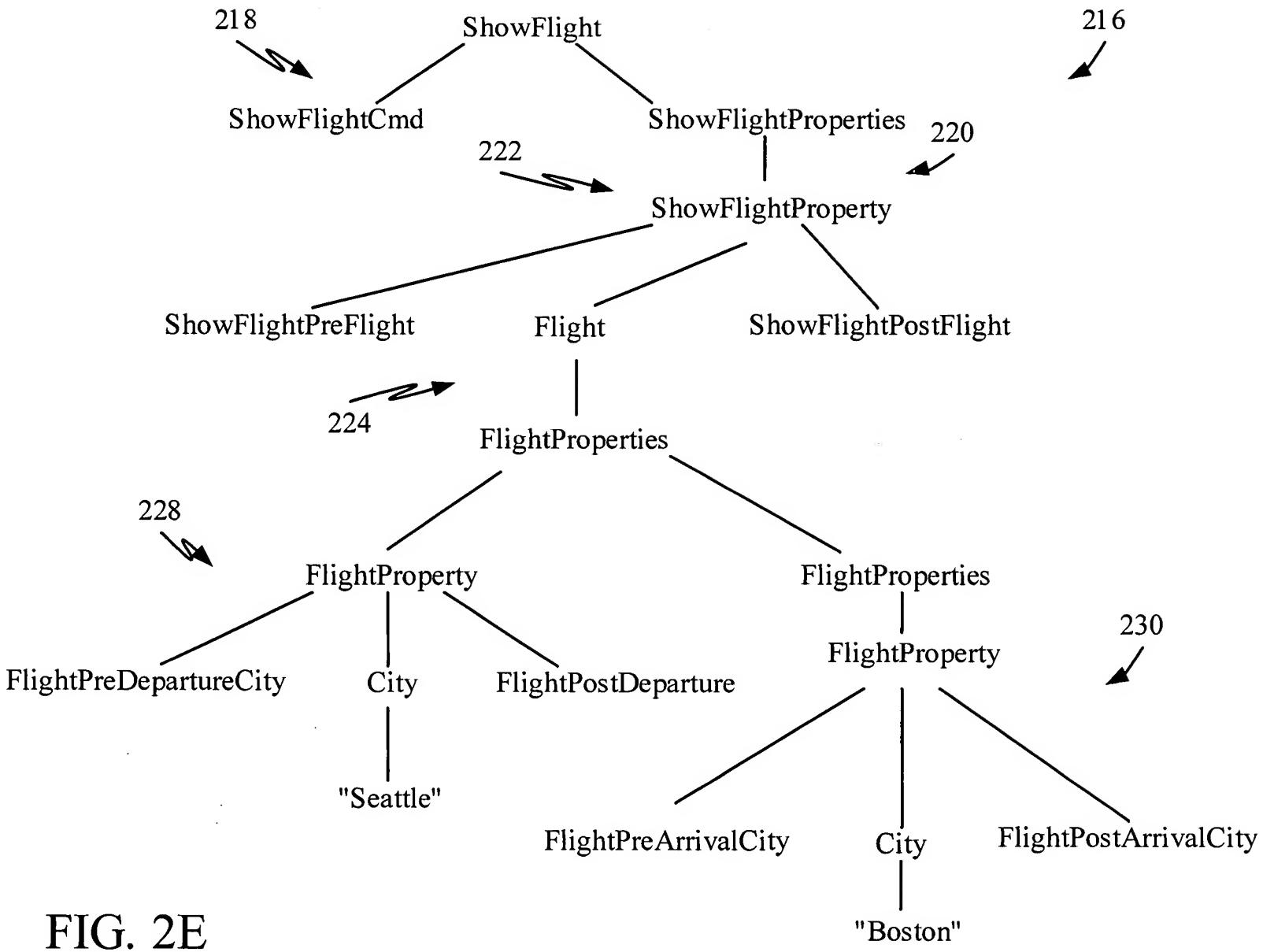

218
ShowFlight
216
ShowFlightCmd
ShowFlightProperties
220
222
ShowFlightProperty
ShowFlightPreFlight
Flight
ShowFlightPostFlight
224
FlightProperties
228
FlightProperty
FlightProperties
230
FlightProperty
FlightPreDepartureCity
City
FlightPostDeparture
"Seattle"
FlightPreArrivalCity
City
FlightPostArrivalCity
"Boston"

FIG. 2E

Example	Possible Preterminals	
From	ShowFlightCmd	FlightPreDepartureCity
Flight from	ShowFlightCmd	FlightPreDepartureCity
Flight to	ShowFlightCmd	FlightPreArrivalCity

FIG. 2F

Possible Re-write Rule	Count	Probability	$\bar{C}$
SFCmd→ ε (empty set)	1/2+1/3+1/3=7/6	7/18	7/10
SFCmd→ from	1/2=3/6	3/18	3/10
SFCmd→ flight	1/3+1/3=4/6	4/18	⋮
SFCmd→ flight from	1/3=2/6	2/18	
SFCmd→ flight to	1/3=2/6	2/18	
FPDCity→ ε	1/2+1/3=5/6	5/12	
FPDCity→ from	1/2+1/3=5/6	5/12	
FPDCity→ flight from	1/3=2/6	2/12	
FPACity→ ε	1/3=1/3	1/3	
FPACity→ to	1/3=1/3	1/3	
FPACity→ flight to	1/3=1/3	1/3	

FIG. 2G

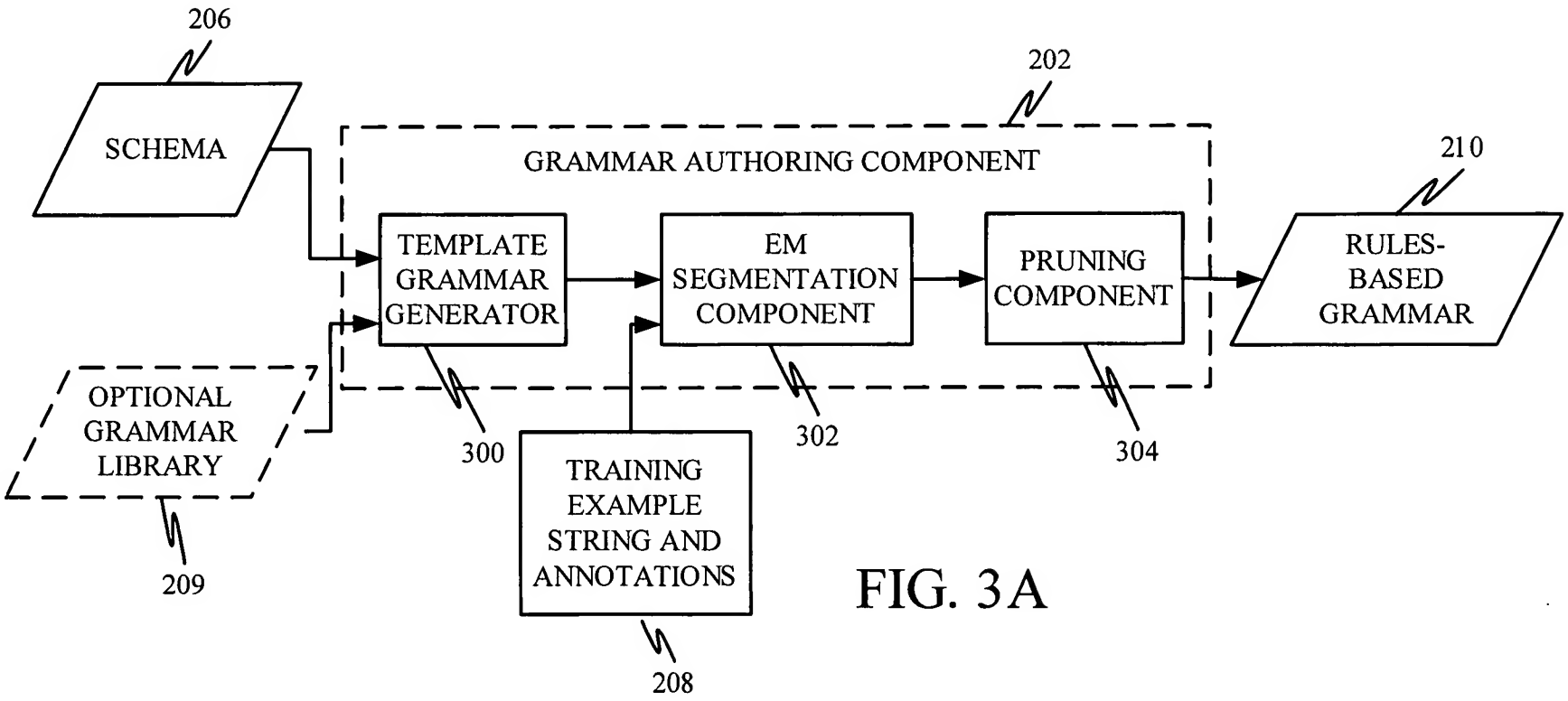

206
SCHEMA
202
GRAMMAR AUTHORING COMPONENT
210
TEMPLATE GRAMMAR GENERATOR
EM SEGMENTATION COMPONENT
PRUNING COMPONENT
RULES-BASED GRAMMAR
OPTIONAL GRAMMAR LIBRARY
300
302
304
209
TRAINING EXAMPLE STRING AND ANNOTATIONS
208

FIG. 3A

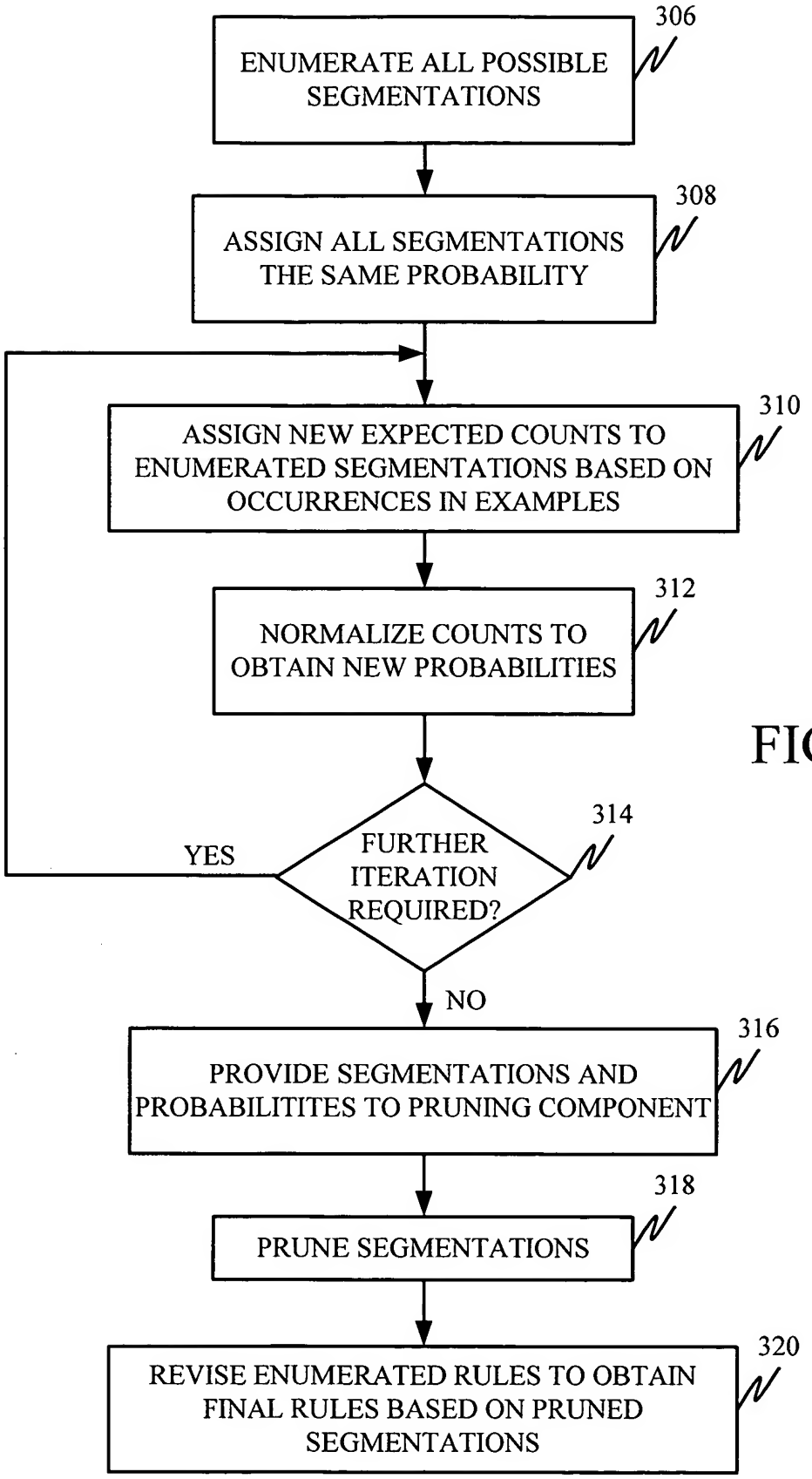

306
ENUMERATE ALL POSSIBLE SEGMENTATIONS
308
ASSIGN ALL SEGMENTATIONS THE SAME PROBABILITY
310
ASSIGN NEW EXPECTED COUNTS TO ENUMERATED SEGMENTATIONS BASED ON OCCURRENCES IN EXAMPLES
312
NORMALIZE COUNTS TO OBTAIN NEW PROBABILITIES
314
FURTHER ITERATION REQUIRED?
YES
NO
316
PROVIDE SEGMENTATIONS AND PROBABILITITES TO PRUNING COMPONENT
318
PRUNE SEGMENTATIONS
320
REVISE ENUMERATED RULES TO OBTAIN FINAL RULES BASED ON PRUNED SEGMENTATIONS

FIG. 3B

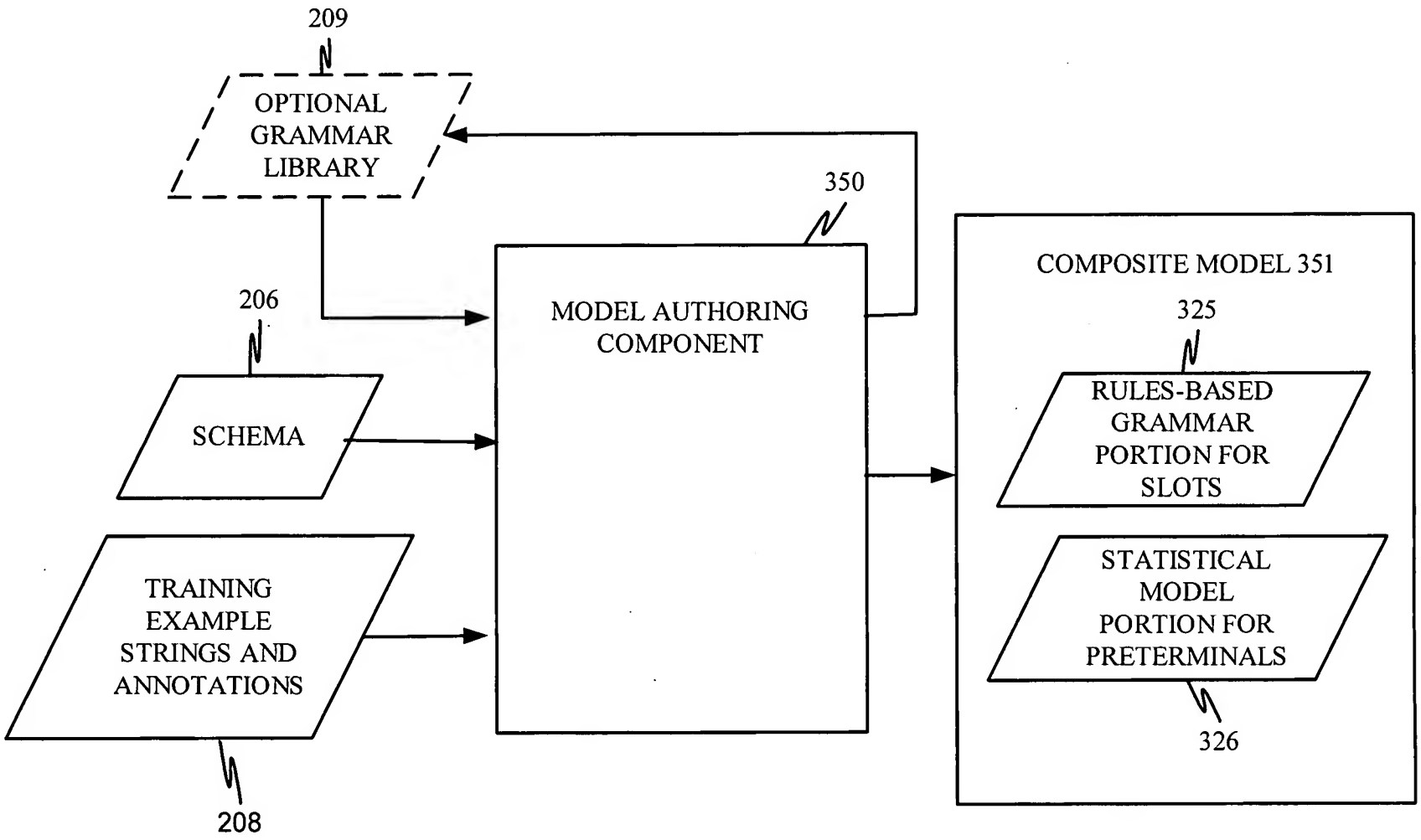

209
OPTIONAL GRAMMAR LIBRARY
350
206
MODEL AUTHORING COMPONENT
COMPOSITE MODEL 351
325
SCHEMA
RULES-BASED GRAMMAR PORTION FOR SLOTS
STATISTICAL MODEL PORTION FOR PRETERMINALS
TRAINING EXAMPLE STRINGS AND ANNOTATIONS
326
208

FIG. 4

ShowFlightCmd→ε
ShowFlightCmd→show
ShowFlightCmd→show me
ShowFlightCmd→show me the
ShowFlightCmd→show me the flight

FIG. 5

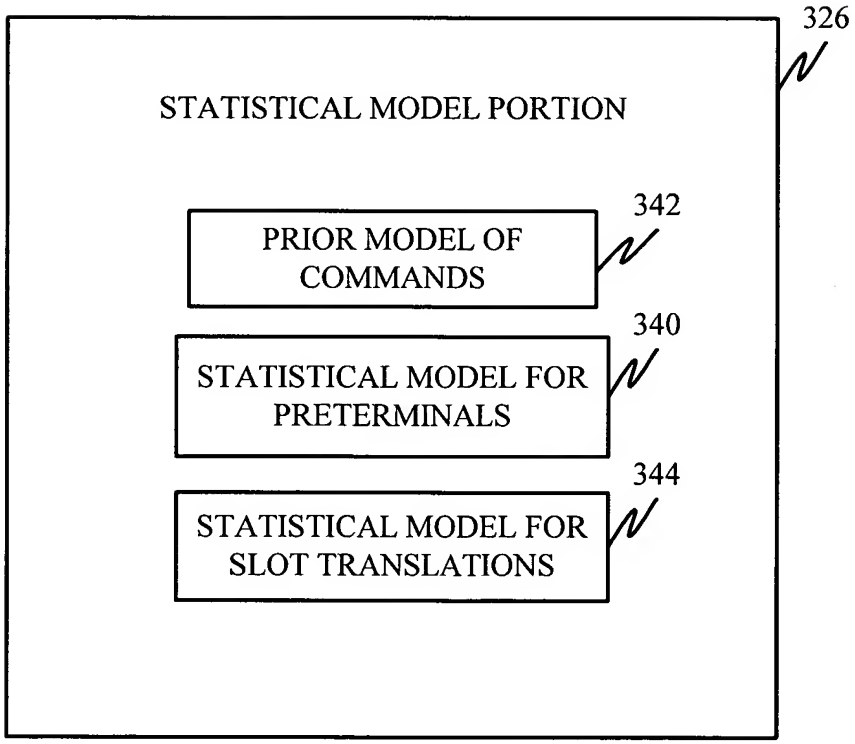


FIG. 6

```
<command name="NewAppt">
    <slot type="Person" name="Attendee"/>
    <slot type="Time" name="StartTime"/>
</command>
```

FIG. 7

```
<C_NewAppt> → <NewApptCmd> {<NewApptProperties>}
<NewApptProperties> → <NewApptProperty>
                        {<NewApptProperties>}
<NewApptProperty> → <NewApptAttendeeProperty> |
                    <NewApptStartTimeProperty>
<NewApptAttendeeProperty> →
      {<PreAttendee>} <Person> {<PostAttendee>}
<NewApptStartTimeProperty> →
      {<PreStartTime>} <Time> {<PostStartTime>}
```

FIG. 8

```
<NewAppt>
   <Attendee type="Person">Peter</Attendee>
   <StartTime type="Time">five</StartTime>
</NewAppt>
```

FIG. 9

```
<NewApptCmd> → new meeting
<PreAttendee> → with
```

FIG. 10

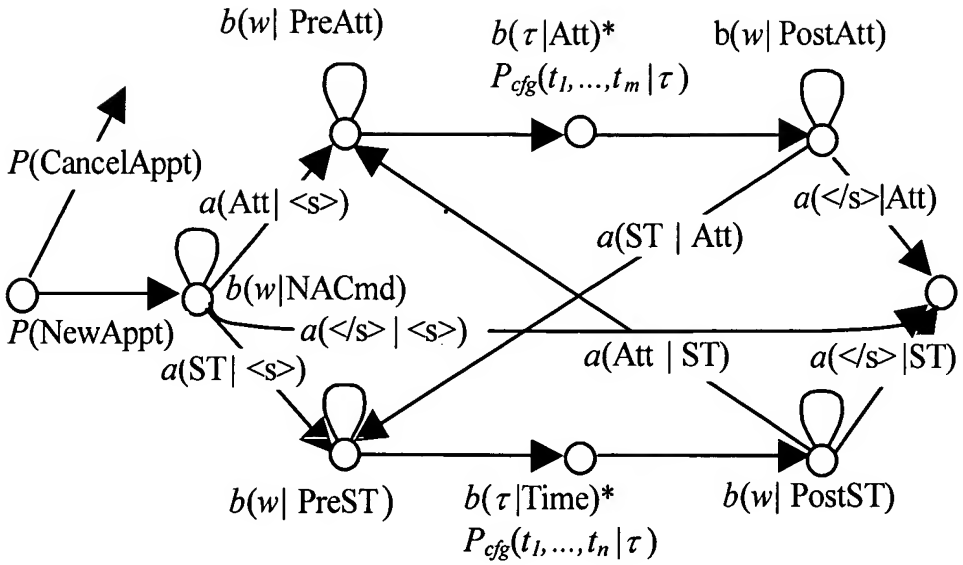


FIG. 11

Initialize the model λ with uniform parameterization
do {
foreach NT→a in λ
Compute the expected count C(NT→a) with dynamic programming
foreach *NT,* set its n-gram parameters in the new model λ':
Partition all the rules for NT into training and held-out sets;
For the rules NT→a in the training set, train the n-gram model for
NT using $_a$ with the expected count C(NT→a)
Estimate the model smoothing parameters with the held-out counts via
deleted interpolation.
} **while** (Perplexity(Sample |λ) – Perplexity(Sample | λ') > threshold)

FIG. 12

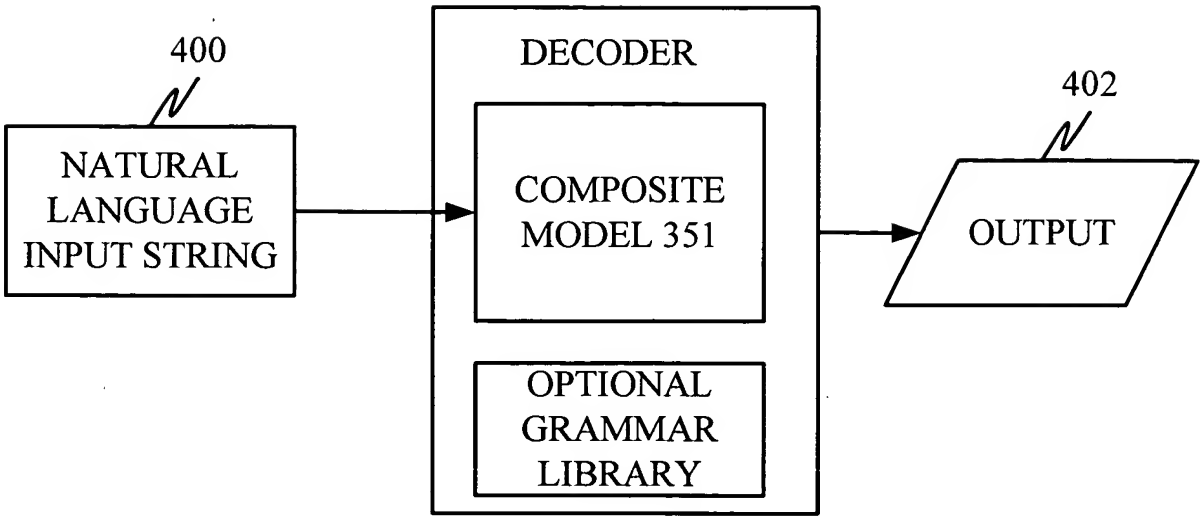

400
NATURAL LANGUAGE INPUT STRING
DECODER
COMPOSITE MODEL 351
OPTIONAL GRAMMAR LIBRARY
402
OUTPUT

FIG. 13

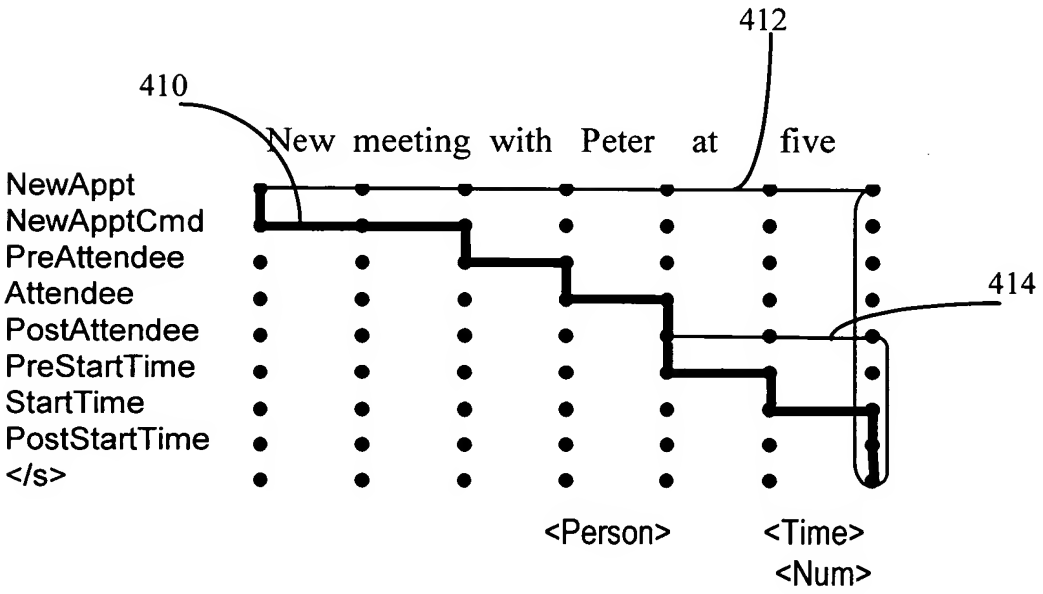

412
410
New meeting with Peter at five
NewAppt
NewApptCmd
PreAttendee
Attendee
PostAttendee
PreStartTime
StartTime
PostStartTime
</s>
414
<Person>
<Time>
<Num>

FIG. 14

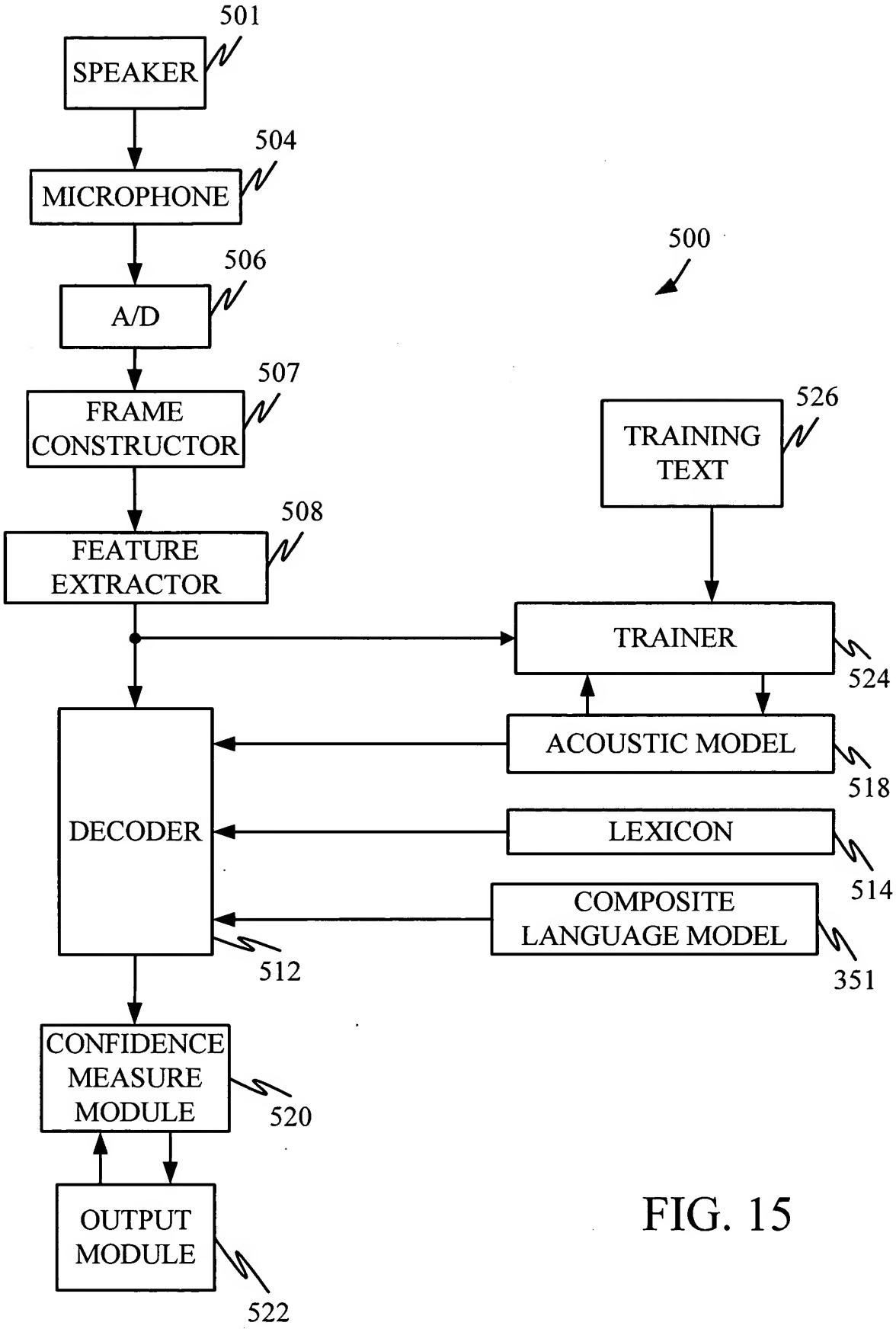

501
SPEAKER
504
MICROPHONE
506
A/D
507
FRAME CONSTRUCTOR
508
FEATURE EXTRACTOR
500
526
TRAINING TEXT
TRAINER
524
ACOUSTIC MODEL
518
DECODER
LEXICON
514
COMPOSITE LANGUAGE MODEL
351
512
CONFIDENCE MEASURE MODULE
520
OUTPUT MODULE
522

FIG. 15

600

```
<task name = "ShowFlight">
        <slot type = "City" name = "ACity"/>
        <slot type = "City" name = "DCity"/>
</task>
<task name = "GroundTransport">
        <slot type = "City" name = "City"/>
        <slot type = "Transport_Type" name = "TType"/>
</Task>
```

FIG. 16

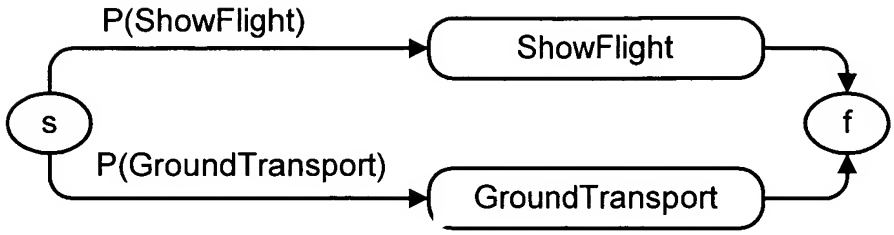


FIG. 17A

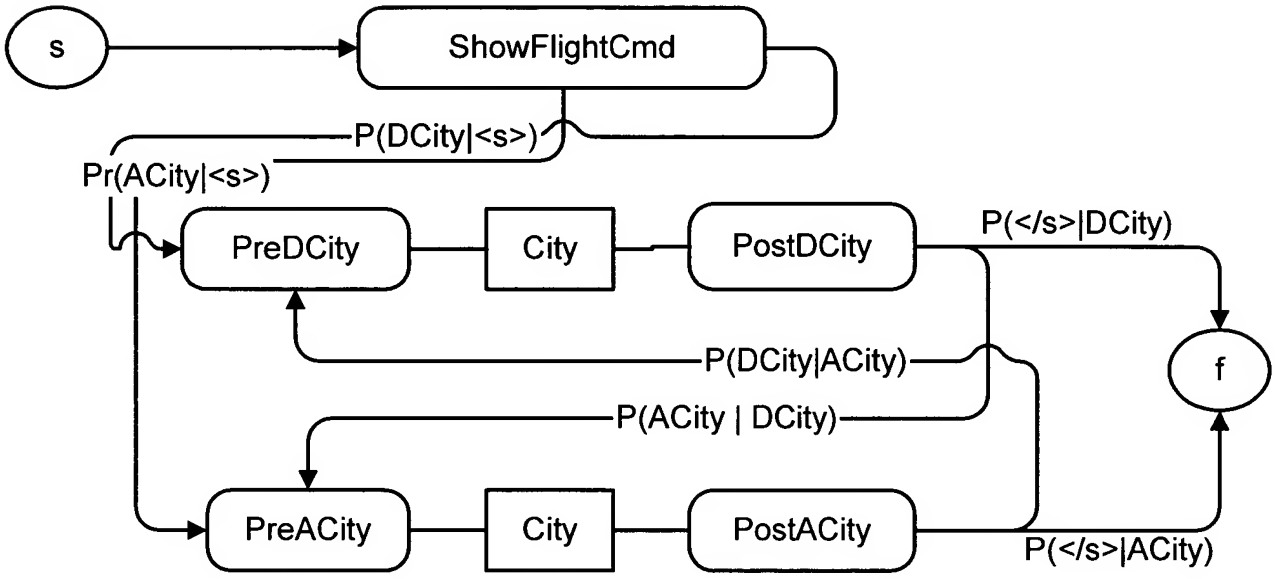


FIG. 17B

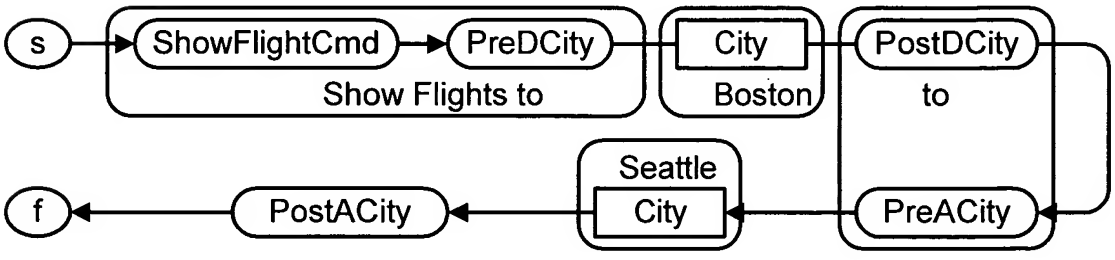
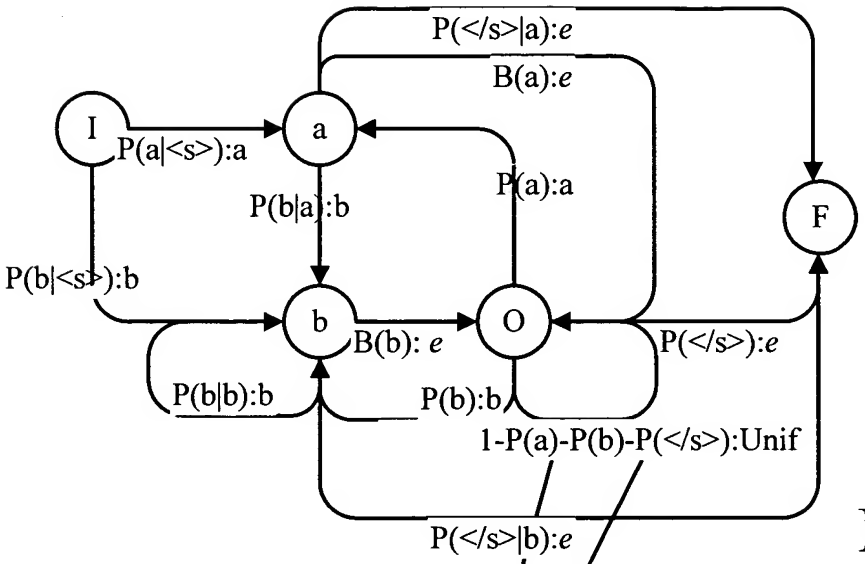
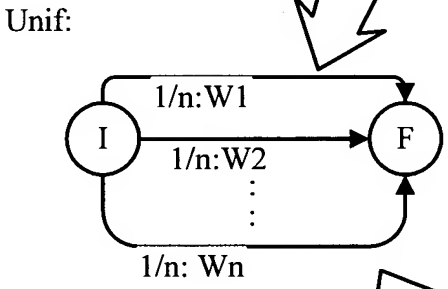


FIG. 17C



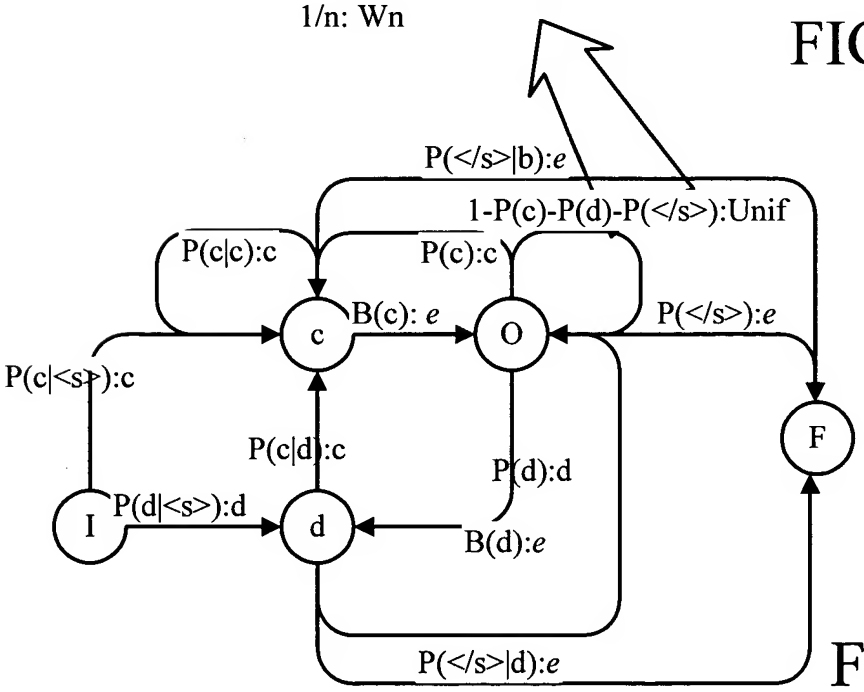
(a)

FIG. 18A



(b)

FIG. 18B



(c)

FIG. 18C